Y-12

OAK RIDGE
Y-12
PLANT

MARTIN MARIETTA

Y/EN-1837

STACK RADIOLOGICAL MONITORING PROJECT

BREAKTHROUGH MONITOR STARTUP REPORT

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FOR THE UNITED STATES
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CONTENTS

PREFACE

This report concerns the Nuclear Measurements Corporation Breakthrough Monitors (BTMs) installed at the Y-12 Plant by the Stack Radiological Monitoring Project. The purpose of the report is to document the calibration and checking procedures developed specifically for Y-12 stack monitoring. This report should be used to supplement the Nuclear Measurement Corporation Instruction Manual. The author gratefully acknowledges J. E. Powell, Health, Safety, Environment, and Accountability; J. B. Hunt, Health Physics; L. G. Loden, Process Design Engineering; and S. A. Wallace, Development for the valuable technical input they provided during preparation of the procurement specification for the BTMs; and also W. E. Lever, Statistical Services, for the simulation studies which guided the selection of data processing algorithms and the choice of system parameters finally used in the BTMs at Y-12.

1. INTRODUCTION

Breakthrough monitors (BTMs) were procured and installed on a number of Y-12 process ventilation stacks by the Stack Radiological Monitoring Project. The BTMs are intended to provide a timely warning of abnormally high discharges of uranium particulate matter from these stacks. The cases of abnormally high discharges are referred to as "breakthroughs."

The BTMs are not intended to quantify the amount of uranium discharged from the stacks for purposes of determining compliance with regulations. The BTM filter papers are collected periodically and submitted to the plant laboratory for that purpose.

This report describes calibration and checking procedures developed for BTMs which use X-ray detectors to monitor stacks handling enriched uranium. Calibration procedures for BTMs which use beta detectors to monitor stacks handling depleted uranium are discussed briefly in Appendix E.

2. DESCRIPTION OF THE BREAKTHROUGH MONITOR

The BTM has a constant mass-flow sampling system which draws a representative sample of stack effluent through a fixed filter paper at the rate of one standard cubic foot per minute. The accumulation of uranium particulate matter on the filter paper is sensed by an X-ray detector facing the spot where the particulate matter is being collected.

A high alarm is generated when the rate of accumulation exceeds the set point for a sufficient period of time. The time to alarm is more or less inversely proportional to the magnitude of the breakthrough.

3. ALARM LEVEL

The following example is given to clarify the concept of BTM alarm level. In this example it is assumed that the stack effluent is at standard conditions. Given the description of the BTM in Sect. 2, it follows that if the concentration of uranium particulates in the stack effluent is 1 pCi/ft^3, then 1 pCi of uranium will be deposited on the filter per minute. Using the definition that 1 Ci of activity is 3.7×10^{10} disintegrations per second, the buildup of uranium activity on the filter paper is calculated to be 2.2 disintegrations per minute per minute (d/min/min). This buildup of activity on the filter paper is referred to as the slope. The BTM high alarm set point is in units of <u>counts</u> per minute per minute, which is directly proportional to the slope.

A design goal set for the BTM was to generate an alarm within 1 h in response to a slope of 50 d/min/min. The alarm level of 50 d/min/min can be translated to equivalent levels; i.e., equivalent 22.5 pCi/ft^3 of stack effluent, or 0.41 μg of enriched uranium per cubic foot of stack effluent. The translation to micrograms of enriched uranium assumes an enrichment to 93% ^{235}U, for which the specific activity is 122 d/min/μg (^{234}U contributes the majority of this activity).

Experience with particulate sampling systems has shown that some fraction of the particulates are lost in the sample lines, and this loss was not taken into account in the above calculations. If a typical sample line loss of 2/3 is assumed, then the stack concentration needed to trigger the 50 d/min/min alarm would be three times greater than computed above; i.e., 150 d/min/min, 67.5 pCi or 1.23 μg of enriched uranium per cubic foot of stack effluent. A thorough discussion of the Y-12 stack monitoring application is given in Ref. 1. In this reference, an alarm level of 70 pCi/ft^3 of stack effluent and an alarm response time of 1 h is shown to be useful for stack monitoring at Y-12. It should be noted that for a given concentration of uranium in the stack effluent, the uranium discharge rate is proportional to stack flow. For example, a stack with a flow of 10,000 scfm and a concentration of 1.23 μg enriched uranium per cubic foot will lose a total of 0.73 g/h, while a stack with the same concentration but a flow of 100,000 scfm will lose a total of 7.3 g/h.

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[1]Rubel, P., "Breakthrough Monitor Prototype Application at the Y-12 Plant," Y/EN-1673, October 1986.

4. CALIBRATION

The chief complexity in calibrating the X-ray type BTM is in determining the parameters for the Variable Background Correction algorithm. This algorithm produces uranium counts which are independent of radon daughter activity. The BTM has the capability of rejecting the activity of one other radioactive isotope in the sample should that become necessary. In this report, the radon daughter activity will be referred simply as radon activity.

The X-ray spectrums for enriched uranium and radon daughters obtained with a laboratory-type 3-in.-diam x 3-in.-thick NaI(Tl) detector are shown in Fig. 1. An X-ray spectrum for enriched uranium obtained with a BTM X-ray detector is shown in Fig. 2. The enriched uranium spectrums obtained with the two types of detectors are very similar. Presumably the same would be true of radon spectrums but atmospheric radon levels have been too low since the BTMs were installed to verify this. Looking at the spectrums in Fig. 1, it is easy to see why counts in the uranium window are affected by the radon activity. The radon spectrum has a relatively high tail in the energy range of the uranium peak. The two peaks are shown graphically about equal in height; but in reality, the radon peak can be much higher than the uranium peak, in which case the radon tail would add significantly to the uranium count.

The BTM is equipped with three single-channel analyzers, one adjusted for uranium, one for radon, and a third one available for some other interfering isotope. The uranium window is set for 8 to 40 KeV and

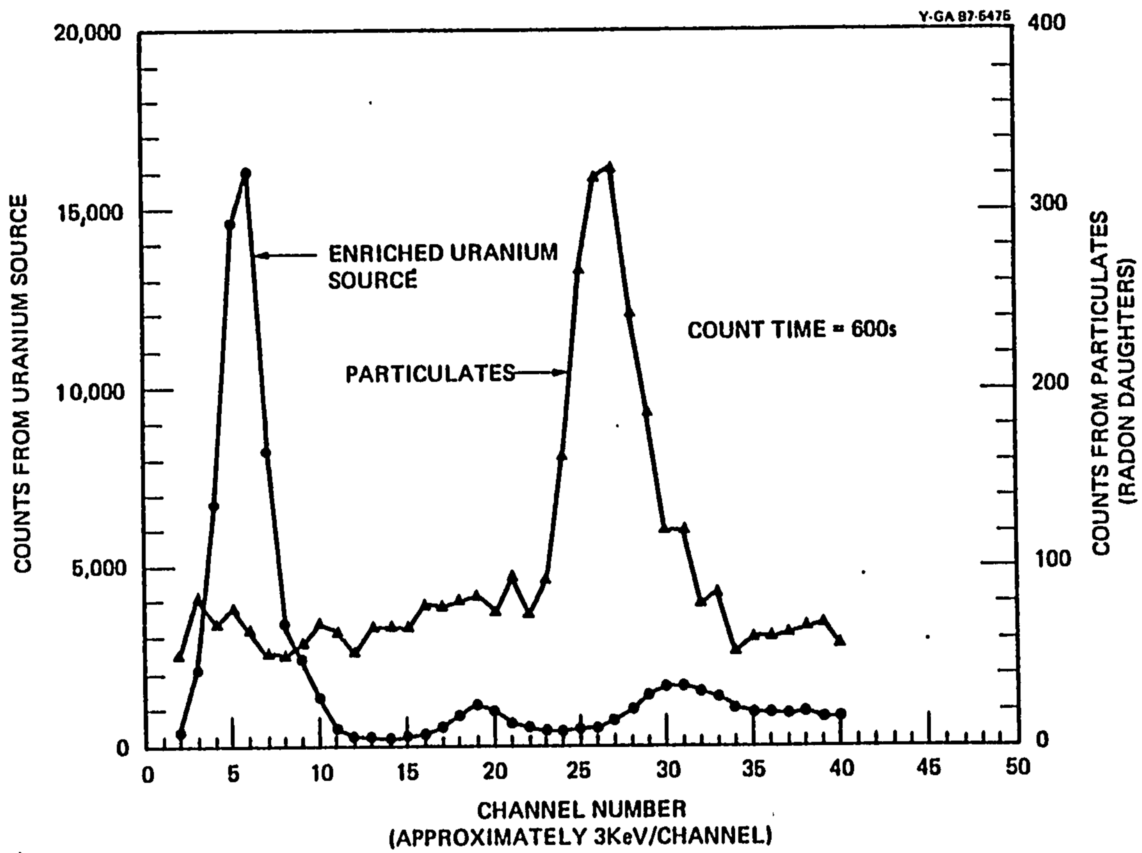

Figure 1. X-RAY ENERGY SPECTRUMS FROM A 100,000 d/min ENRICHED URANIUM SOURCE (93% U-235) AND FROM PARTICULATES FILTERED FROM A 5 m^3 ROOM AIR SAMPLE. TAKEN WITH A 3" DIAM X 3" THICK NaI(Tl) LABORATORY TYPE DETECTOR.

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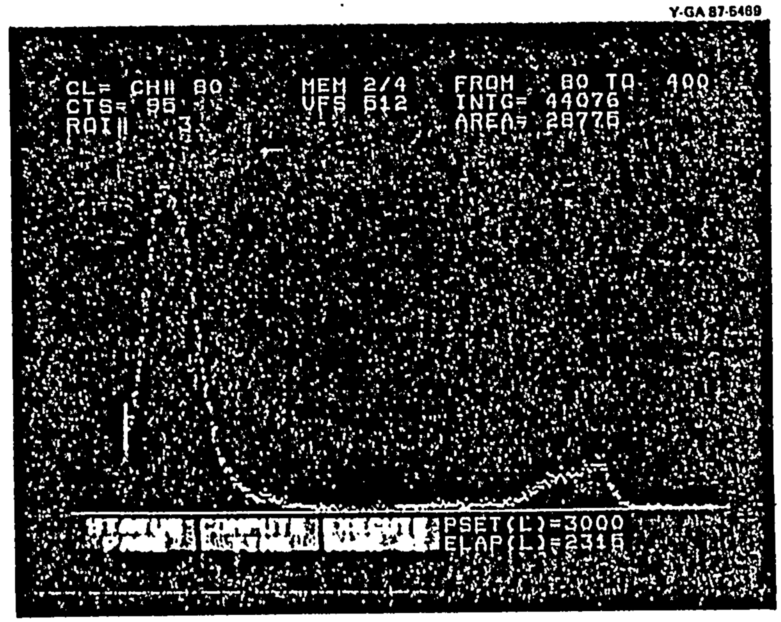

Figure 2. X-RAY ENERGY SPECTRUM FROM A 30,000 d/min ENRICHED URANIUM SOURCE (93% U-235). TAKEN WITH AN NMC BREAK-THROUGH MONITOR X-RAY DETECTOR. MULTICHANNEL ANALYZER DATA: 1000 CHANNELS, 0-100 KeV, COUNT TIME = 2315 s.

the radon window is set for 50 to 100 KeV. The procedure for adjusting the windows can be found in the NMC instruction manual. The BTMs are calibrated with a plated enriched uranium source of known strength and with a natural radon source collected on a filter paper. It is not necessary to know the strength of the radon activity used for calibration because the BTM is not required to measure the radon activity during operation, but only to prevent it from being counted as uranium. This is accomplished with a simple algebraic spectrum unfolding algorithm, the details of which are described in Procedure 2, Calibration of X-ray-Type Breakthrough Monitors (Appendix B). Procedure 1, Terms and Coefficients for X-ray-Type Breakthrough Monitors (Appendix A), is used to take calibration data and compute coefficients used in Procedure 2. In general, calibration consists of taking count data from the uranium and radon windows under the following conditions: (1) with a clean filter paper, (2) with the calibrated enriched uranium source, and (3) with the uncalibrated radon source. With this count data, the appropriate parameters are computed and installed in the NMC Variable Background Correction algorithm.

5. ALARM RESPONSE CHARACTERISTICS

The response times of alarm instruments are usually fast enough to track the process variable and one need only to be concerned with the alarm set point. This is not the case with the BTM, however, because the time constants needed to smooth out the statistical fluctuations in the process variables (counts per minute and counts per minute per minute) are quite long. Therefore, when considering a BTM alarm set point, it is necessary to also consider the response time characteristics. The criteria that an alarm be generated X h after the concentration of enriched uranium in the stack effluent goes to Y μg/ft^3 does not lead to a unique set of values for the BTM alarm set point and time constants. Statistical performance of BTM alarm response time is not amenable to analysis because of the Poisson distribution of the low counts involved and the algebraic operations on those counts to compute the uranium count rate and the slope. To deal with this, W. E. Lever suggested modeling the system mathematically and investigating the alarm response time statistics by running cases with simulated count data. A model was developed which consists of the NMC algorithms for computing count rate and rate of change in count rate and the equations for Case 2 of Procedure 2 (Appendix B) which model the radiation detector, single-channel analyzers, and variable background correction components of the BTM. In the analysis, model parameters associated with response to a uranium source were set to values typical of measured results from the BTMs. The values for parameters associated with radon were only estimates because observed radon levels were too low to obtain measured values. Important results obtained by W. E. Lever are presented in Sects. 7.1, 7.2, 7.3, and 7.4.

5.1 TIME TO ALARM VS SIZE OF THE BREAKTHROUGH

The algorithms furnished by NMC to compute the uranium count rate and the rate of change in count rate are described in a report by William C. Evans.[2] A system block diagram and the algorithms are shown in Fig. 3. The smoothing constant ALPHA is computed internally as a function of a "tracking variable" described in the Evans report. The net effect of ALPHA being a computed variable is that the count rate smoothing time constant is lengthened or shortened to the extent that the rate output, AT, is tracking or not tracking the incoming data stream, Su/p. The count rate smoothing algorithm is called "adaptive" because of the internal computation of the smoothing constant ALPHA. The adaptive algorithm was suggested by NMC as possibly a way for Y-12 to get fast alarm responses to large breakthroughs and slower (but still reliable) alarm responses to small breakthroughs. There was considerable uncertainty about the statistical characteristics of the tracking signal so the alarm response time characteristics with the adaptive features disabled were studied. During the study, two sets of parameters were found which gave satisfactory results. The first set, given in Table 1, was installed in the BTMs during the engineering startup. The other set, given in Table 5, was installed in the BTMs for routine operations.

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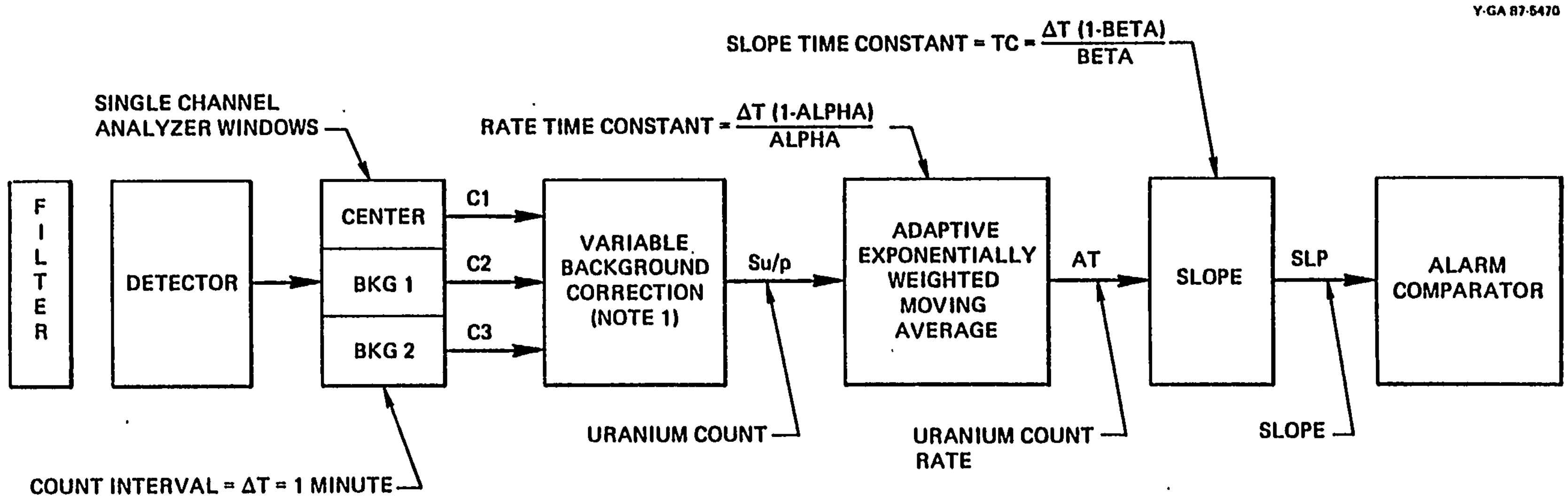
[2] Evans, William C., "Digital Countrate Estimation Using Adaptive Exponentially-Weighted Moving Averages," American Nuclear Society, 25th Annual Meeting, Atlanta, Georgia, June 1979.



NOTES:

1. SEE PROCEDURE 2, "CALIBRATION OF X-RAY TYPE BREAKTHROUGH MONITORS" FOR ALGORITHM TO COMPUTE THE URANIUM COUNT.

NMC ALGORITHMS

1. AT(i) = ALPHA*(Su/p)(i) + (1-ALPHA)*AT(i-1)
2. S2(i) = BETA*AT(i) + (1-BETA)*S2(i-1)
3. SLP(i) = [AT(i)-S2(i)]/TC
   (IN THE NMC SYSTEM, ΔT = 1 AND BETA << 1, SO IN EQ. 2 THE APPROXIMATION IS MADE THAT BETA = 1/TC.

Figure 3. SYSTEM BLOCK DIAGRAM AND ALGORITHMS.

Table 1. System parameters used during engineering startup

Count interval	1 min (built into NMC BTM)
Rate time constant	15 min (i.e., alpha = 0.0625)
Slope time constant	300 min
Slope alarm set point	5 d/min/min
Calibration coefficients: (Note 1)	
b	9
e	0.0385
h	513/X (Note 2)
c	12
f	0.0044
i	356/X (Note 2)

Notes:

1. See Procedure 2, Case 2 for definition of calibration coefficients.

2. X is the assumed worst-case, steady-state radon daughter activity on the filter paper. For simulation studies, the radon activity, E(t), was assumed to build up on the filter paper with a half-hour time constant; for example:

$$E(t) = E(1-e^{-t/30}),$$

where

t = time in min.

For the worst-case radon background:

$$E(t) = X(1-e^{-t/30}).$$

The computed statistical characteristics of the time to alarm vs slope are shown in Fig. 4 and Table 2 for the system parameters used during the engineering startup. The system parameters are given in Table 1. The results shown in Fig. 4 and Table 2 were obtained by W. E. Lever by running 200 cases for each of 20 constant slopes ranging from 5 to 100 d/min/min. For a slope of 50 d/min/min, the median time to alarm is 0.85 h and the range is 0.77 to 0.95 h. This is consistent with the original goal discussed in Sect. 3. Figure 4 shows that the time to alarm is more or less inversely proportional to the size of the breakthrough.

5.2 UNWANTED ALARMS DUE TO COUNTING STATISTICS

To examine the question of unwanted alarms due to counting statistics, the system parameters of Table 1 are used again. The results from 20 cases run for each of a number of slopes below the high alarm set point are shown in Table 3. The data in the table show no alarms from slopes of 2 and 3 d/min/min; however, there were some alarms from a slope of 4 d/min/min. The performance represented by the data in Table 3 is considered acceptable.

5.3 CHECKING ALARM RESPONSE WITH A RADIOACTIVE SOURCE

The BTM is designed to alarm in response to a buildup of uranium on the filter (i.e., a slope). The only slope that can be conveniently

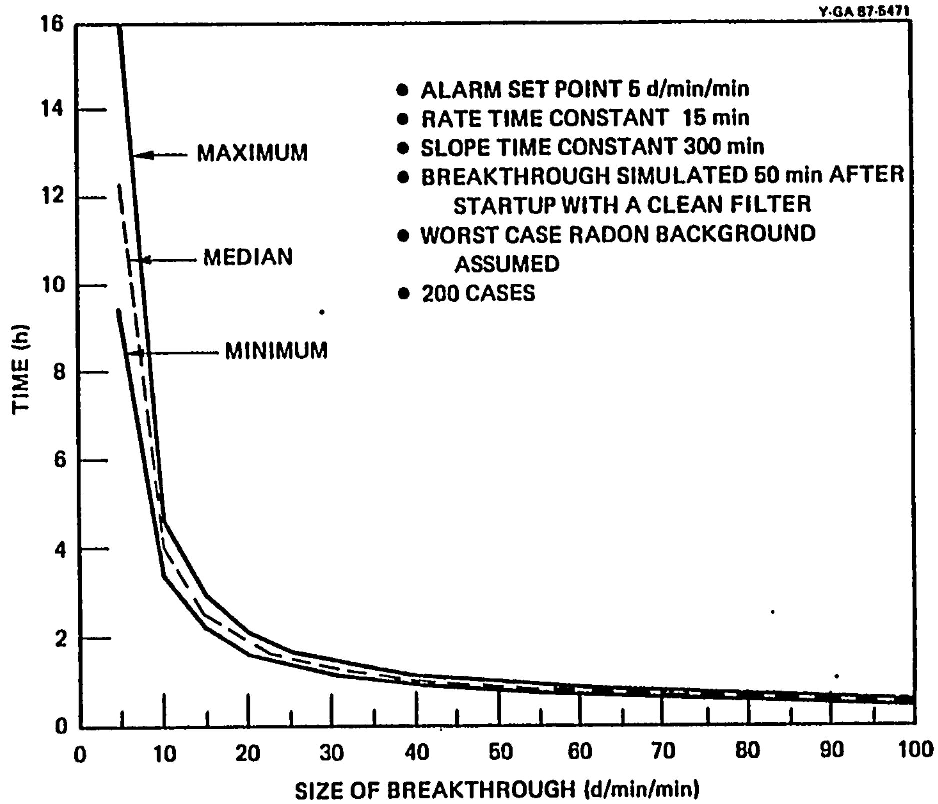


Figure 4. TIME TO ALARM FOLLOWING A SIMULATED BREAKTHROUGH vs. SIZE OF THE BREAKTHROUGH, WITH SYSTEM PARAMETERS USED DURING ENGINEERING STARTUP

Table 2. Computed time to alarm following a simulated breakthrough vs the breakthrough induced slope (d/min/min), with system parameters used during the engineering startup.

Breakthrough induced slope (d/min/min)	Time to alarm (h)	
	Median	Range
5	12.3	9.4 - 15.9
10	4.0	3.4 - 4.6
15	2.5	2.2 - 2.9
20	1.9	1.6 - 2.1
25	1.5	1.4 - 1.7
30	1.3	1.1 - 1.5
35	1.2	1.0 - 1.3
40	1.0	0.9 - 1.1
45	0.92	0.83 - 1.03
50	0.85	0.77 - 0.95
55	0.79	0.72 - 0.88
60	0.74	0.67 - 0.85
65	0.70	0.63 - 0.78
70	0.66	0.60 - 0.73
75	0.63	0.55 - 0.70
80	0.60	0.53 - 0.67
85	0.57	0.52 - 0.63
90	0.55	0.50 - 0.63
95	0.53	0.48 - 0.58
100	0.50	0.47 - 0.57

Notes:

Number of cases = 200.

Alarm set point = 5 d/min/min.

Rate time constant = 15 min, slope time constant = 300 min, breakthrough simulated 50 min after startup with clean filter paper, worst-case radon background.

Table 3. Simulation study of unwanted alarms due to counting statistics, with system parameters used during engineering startup

Slope (d/min/min)	Time to alarm (h)		
	Mean	Std. deviation	Range
2	No alarms		
3	No alarms		
4	40.8	11.4	16.8 - 63.2
5	12.3	1.21	9.9 - 14.6

Notes:

Number of cases = 20 for each slope.

Alarms set point = 5 d/min/min, rate time constant = 15 min, slope time constant = 300 min, worst-case radon background.

simulated with a radioactive source is an impulse (i.e., the slope is zero before and after the source is inserted but undergoes an impulse during the insertion). As discussed in Sect. 5.1, the adaptive feature of the NMC rate algorithm was disabled so the system has a well-defined and predictable transient response. Therefore, the transient response of the BTM to insertion of a source is predictable and provides a convenient way to check the overall performance of the system. Figure 5 shows the mean value of the transient responses from 200 simulated source insertion cases run by W. E. Lever, again for the system parameters shown in Table 1. As shown in Fig. 5, the mean transient response is large enough to to activate the alarm. Table 4 shows the frequency distribution of the alarm times obtained from 200 additional simulation runs. For these runs, the simulated source strength was 3,000 d/min, and the alarm threshold was set at 0.229 c/min/min (5.945 d/min/min). The computed mean time to alarm following source insertion was 15 min, and the standard deviation was 0.6 min. A detailed procedure for using results like this to check the BTM alarm response is given in the next section.

5.4 CHANGING SYSTEM PARAMETERS

Whenever the high alarm set point or any of the system time constants is changed, the alarm response times and the alarm statistics should be reevaluated to make sure they are satisfactory. This was done after the engineering startup and before the system was put into routine operation. The alarm level was changed from 5 d/min/min to 50 d/min/min

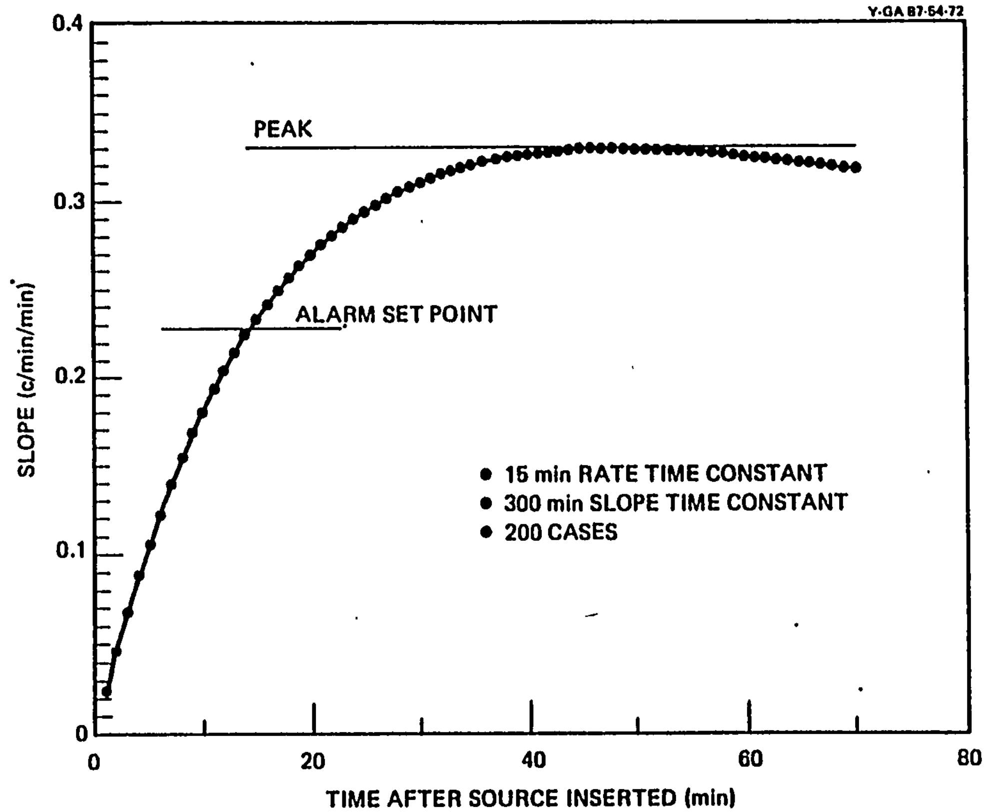


Figure 5. SIMULATION RESULTS FOR MEAN SLOPE vs. TIME AFTER INSERTION OF A 3,000 d/min ENRICHED URANIUM SOURCE, FOR SYSTEM PARAMETERS USED DURING ENGINEERING STARTUP

Table 4. Frequency distribution of predicted time to alarm following insertion of a 3,000-d/min enriched uranium source with system time constants used during engineering startup except that for these simulations, the alarm set point was 5.945 instead of 5.0 d/min/min

Time to alarm (min)	Frequency
14	39
15	127
16	33
17	1
Total number of runs	200

Note:

Rate time constant = 15 min, slope time constant = 300 min, and alarm set point = 5.945 d/min/min.

and the slope time constant was changed to 20 min. The rate time constant was left unchanged at 15 min. The full set of system parameters installed for routine operations are given in Table 5. Using these parameters, the alarm response time was investigated with 200 simulated runs. The results are shown in Fig. 6 and Table 6. The median alarm response time for a slope of 50 d/min/min was 1.48 h. The pattern of alarm response times for slopes above the high alarm set point is considered satisfactory as are the instances of unwanted alarms for slopes below the high alarm set point.

Whenever system parameters are changed, it is also necessary to update the procedure for checking the overall performance with a radioactive source. This was done for system parameters installed for routine operations. First, the transient response of the BTM following insertion of a 3,000-d/min enriched uranium source was studied. The mean value of the transient responses from 200 simulated source insertion runs are shown in Fig. 7. The predicted peak response exceeds the alarm set point of 50 d/min/min (1.93 c/min/min for the units shown in Table 5), so it can be concluded that the 3,000-d/min source is suitable for this check. Next, the frequency distribution of predicted time to alarm following source insertion was determined from another 200 simulation runs. The results are shown in Table 7. For the data in Table 7, the mean time to alarm after the source insertion is 9.1 min, and the standard deviation is 0.6 min. One way to use these data to check the alarm response of the BTM would be to insert a 3,000-d/min enriched uranium source, measure the time for the alarm to occur, and require that this time be equal to the mean value ± some number of standard

Table 5. System parameters used for routine operations

Count interval	1 min (built into NMC BTM)
Rate time constant	15 min (i.e., alpha = 0.0625)
Slope time constant	20 min
Slope alarm set point	50 d/min/min
Calibration coefficients: (Note 1)	
b	9
e	0.0385
h	513/X (Note 2)
c	12
f	0.0044
i	356/X (Note 2)

Notes:

1. See Procedure 2, Case 2 for definition of calibration coefficients.

2. X is the assumed worst-case, steady-state radon daughter activity on the filter paper. For simulation studies, the radon activity, E(t), was assumed to build up on the filter paper with a half-hour time constant; for example:

$$E(t) = E(1-e^{-t/30}),$$

where

t = time in min.

For the worst-case radon background:

$$E(t) = X(1-e^{-t/30}).$$

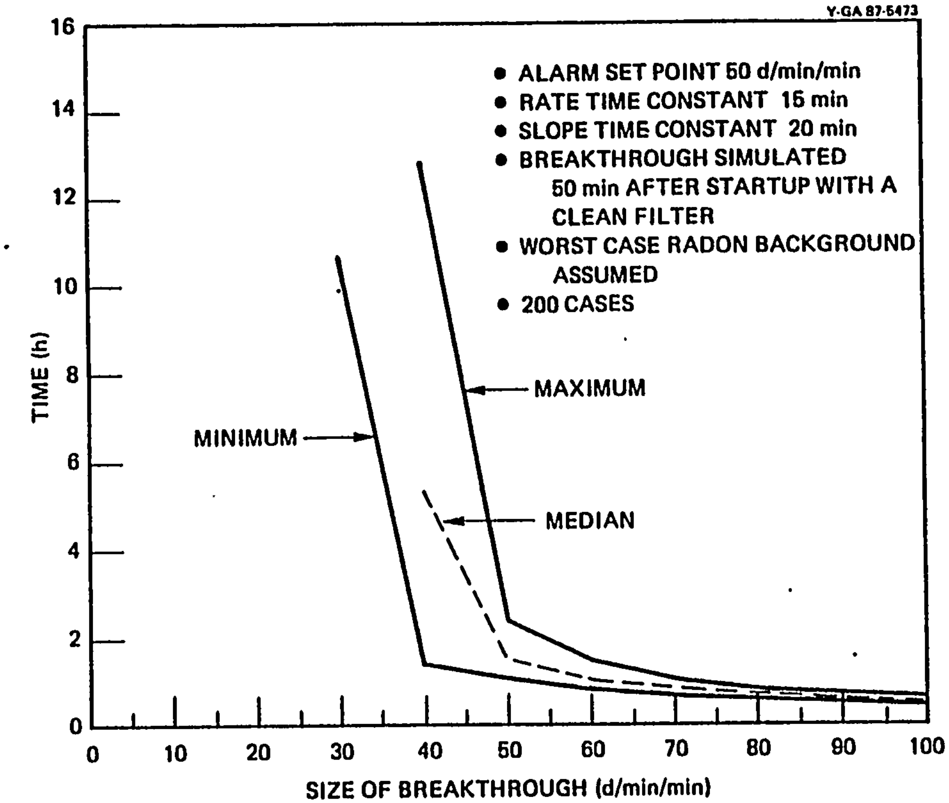


Figure 6. TIME TO ALARM FOLLOWING A SIMULATED BREAKTHROUGH vs. SIZE OF THE BREAKTHROUGH, WITH SYSTEM PARAMETERS USED FOR ROUTINE OPERATIONS

Table 6. Computed time to alarm following a simulated breakthrough vs the breakthrough induced slope (d/min/min), with system parameters used for routine operations

Breakthrough induced slope (d/min/min)	Time to alarm (h)	
	Median	Range
100	0.55	0.47 - 0.65
90	0.62	0.50 - 0.73
80	0.68	0.57 - 0.80
70	0.82	0.65 - 1.03
60	1.02	0.78 - 1.45
50	1.48	1.05 - 2.35
40	5.35	1.40 - 12.8
30	32.8	10.7 - 62.7
20	Infinite	49.0 - Infinite
10	Infinite	Infinite

Notes:

Number of cases = 200.

Alarm set point = 50 d/min/min, rate time constant = 15 min, slope time constant = 20 min, breakthrough simulated 50 min after startup with a clean filter, worst-case radon background.

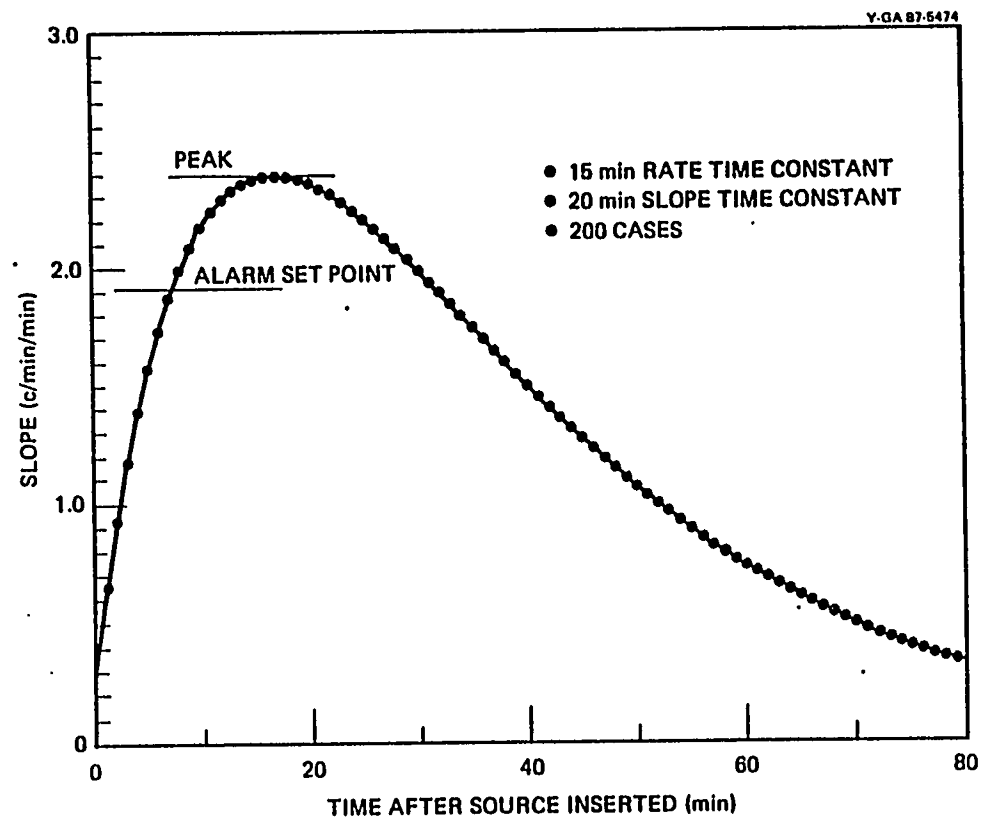


Figure 7. SIMULATION RESULTS FOR MEAN SLOPE vs. TIME AFTER INSERTION OF A 3,000 d/min ENRICHED URANIUM SOURCE, WITH SYSTEM PARAMETERS USED FOR ROUTINE OPERATIONS

Table 7. Frequency distribution of predicted time to alarm following insertion of a 3,000-d/min enriched uranium source, with system parameters used for routine operations

Time to alarm (min)	Frequency
8	24
9	140
10	34
11	2
Total number of runs	200

Note:

Rate time constant = 15 min, slope time constant = 20 min, and alarm set point = 50 d/min/min.

deviations. Several refinements to this have been developed and incorporated into Procedure 3, Checking Alarm Response With an Isotopic Source (Appendix C). The refinements consist of (a) initializing the system after the source is inserted and measuring the time to alarm after the initialization rather than after the source insertion, (b) making some corrections to the actual check source strength to account for a small change in the constant background of the particular BTM being checked, (c) specifying alarm time limits based on 99% confidence that 99% of the alarms will occur within the stated limits, and (d) providing a means to adjust the alarm limits for an allowable drift in BTM sensitivity.

The reasons for initializing the system are twofold. First, it is much more convenient to measure time after initialization because initialization and observation of alarms are both done at the Data Acquisition Module, and also the clock time is available there. More importantly, however, the initialization clears out any memory of activity on the filter paper which is removed before the check source is inserted. The need for this can be seen from the following example. Suppose that the activity on the filter paper is 3,000 d/min because it has been in the BTM for a long time. It is obvious that removing the 3,000-d/min filter paper and inserting the 3,000-d/min source will not produce a useful transient response. Initialization sets the rate and slope algorithms to zero, and the response which follows will be independent of any activity on the removed filter paper.

Another refinement concerns the constant background of the BTM. The routine calibration procedure includes steps to measure the background and then set up the microprocessor to subtract this measured background from all future counts. Over time, the background of the BTM can slowly increase or decrease as contamination levels in the counting chamber change. The background changes are so slow that they do not produce a significant slope alarm response; however, when the BTM is initialized, the background error (i.e., the difference between the actual background and the background offset data in the microprocessor) will appear as a step change and will cause a significant transient response in the slope. In Procedure 3, an estimate of background error is made and the source strength is adjusted to take this into account when the alarm response is checked.

The means for adjusting the alarm time limits for an allowable drift in sensitivity is described in Procedure 3.

APPENDIX A

PROCEDURE 1

STACK RADIOLOGICAL MONITORING PROJECT
TERMS AND COEFFICIENTS FOR X-RAY TYPE
BREAKTHROUGH MONITORS

1. INTRODUCTION

The purpose of this procedure is to obtain source count data from an X-ray type breakthrough monitor (BTM) after the high-voltage and single-channel analyzers are set up. These data are used to compute the Terms and Coefficients b, c, d, e, f, g, h, i, j, k, l, and m, which are used in Procedure 2, Calibration of X-Ray Type Breakthrough Monitors to compute the calibration parameters for the BTM.

2. ACQUIRE DATA

Obtain 15-min average count rates in counts per minute under conditions specified in the following table:

	Window		
	Center (c/min)	Bkg 1 (c/min)	Bkg 2 (c/min)
No Source (Clean Filter Paper)	A______	B______	C______
Uranium Source (Su)*	D______	E______	F______
Radon Source (Sr)**	G______	H______	I______
Other Interfering Source (Si)	J______	K______	L______

*This should be an enriched uranium source, 93% ^{235}U, with a nominal strength of 10,000 d/min.

**The radon source should have sufficient strength to produce nominally 500 c/min from Bkg 1 window.

Note that data are needed only for active windows and sources being calibrated for.

3. COMPUTE TERMS AND COEFFICIENTS

Compute the values for b through m as follows:

b = A	h = (G-A)/Sr
c = B	i = (H-B)/Sr
d = C	j = (I-C)/Sr
e = (D-A)/Su	k = (J-A)/Si
f = (E-B)/Su	l = (K-B)/Si
g = (F-C)/Su	m = (L-C)/Si,

where Su is the calibrated enriched uranium source strength in d/min. Sr and Si are uncalibrated so use the variable names; they will cancel out in the calculation of parameters in Procedure 2.

4. COMPUTE BTM CALIBRATION PARAMETERS

Go to Procedure 2 and compute the values for BKG1 MULT, BKG2 MULT, BKGND OFFSET, and HIGH ALARM. Install these parameters in the BTM using procedures given in the NMC Instruction Manual.

APPENDIX B

PROCEDURE 2

STACK RADIOLOGICAL MONITORING PROJECT

CALIBRATION OF X-RAY TYPE BREAKTHROUGH MONITORS

1. INTRODUCTION

The purpose of this procedure is to get the correct numerical values assigned to the BTM calibration parameters. The list of BTM calibration parameters which must be set up is as follows. Refer to the NMC Instruction Manual for instructions about how to install these parameters.

BKG1 MULT = X.XXX + XX

BKG2 MULT = X.XXX + XX

BKGND OFFSET = X.XXX + XX

Q1 CONST = 1.000 - 01

Q2 CONST = 9.000 - 01

DEL1 CONST = 1.000 - 01

DEL2 CONST = 9.000 - 01

ALPHA CONST = 6.250 - 02

ALPHA LOWER = 6.250 - 02

ALPHA UPPER = 6.250 - 02

TIME CONST = 2.000 + 01

HIGH ALARM = X.XXX + XX cpm/min

LOW COUNT = 1.000 + 00 cpm

LOW FLOW = 5.000 - 01 cfm

The parameters Q1 CONST, Q2 CONST, DEL1 CONST, and DEL2 CONST are used internally by the BTM to compute a tracking variable and multiply it by ALPHA CONST. The resulting value is assigned to the internal variable ALPHA. For the Y-12 stack monitoring application, this computation of ALPHA is nullified by setting the upper and lower bounds on ALPHA (i.e., ALPHA UPPER and ALPHA LOWER) equal to the desired constant value for ALPHA. Even though the computed value for ALPHA is nullified, it is necessary that reasonable values for Q1 CONST, Q2 CONST, DEL1 CONST, DEL2 CONST, and ALPHA CONST be installed to avoid numerical problems. The numerical values shown in the above table are recommended. The value 0.0625 for ALPHA UPPER and ALPHA LOWER results in a rate time constant of 15 min. The slope time constant is entered directly as 20 min with the parameter TIME CONST. These time constant parameters should not be changed without review by the technical staff.

The LOW COUNT alarm is intended to call attention to a failed detector and should be set below the gross counts observed with a clean filter paper. The value of 1 c/min is recommended. The FLOW MAINT alarm is intended to call attention to a low sample flow.

2. PROCEDURES

The procedures for computing numerical values for BKG1 MULT, BKG2 MULT, BKGND OFFSET, and HIGH ALARM are described in this section for four cases, depending on how the BTM is to be used.

2.1 CASE 1 - THREE ACTIVE WINDOWS

In the following equations, C1, C2, and C3 represent the counts obtained in the 1-min count interval from the center window, BKG1 window, and BKG2 window, respectively. The center window is set for uranium, the BKG1 window for radon, and the BKG2 window for some other interfering isotope if needed. Refer to Fig. B1, System Block Diagram and Algorithms, for further clarification.

$$(C1-b) = eSu + hSr + kSi \qquad (1)$$

$$(C2-c) = fSu + iSr + lSi \qquad (2)$$

$$(C3-d) = gSu + jSr + mSi \qquad (3)$$

where

b,c--m = computed terms and coefficients,*

Su = uranium activity (d/min)

Sr = radon activity (d/min),

Si = activity from another interfering radioisotope (d/min).

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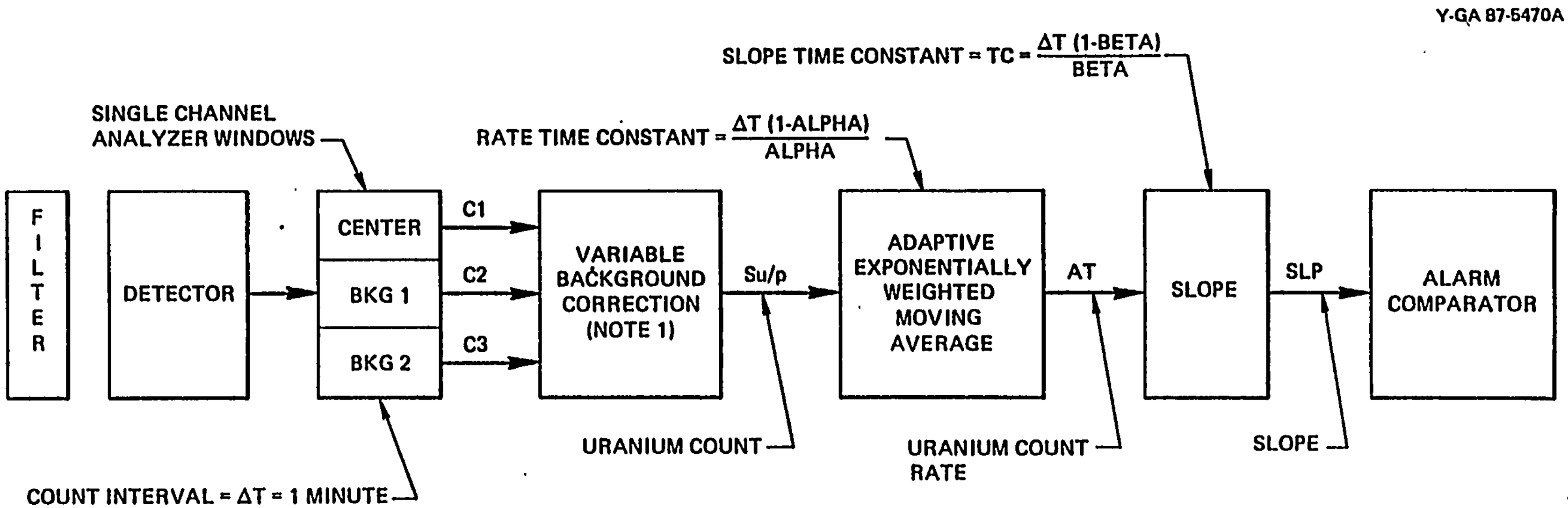
*See Procedure 1, Terms and Coefficients for X-Ray Type Breakthrough Monitors.



NMC ALGORITHMS

1. AT(i) = ALPHA*(Su/p)(i) + (1-ALPHA)*AT(i-1)
2. S2(i) = BETA*AT(i) + (1-BETA)*S2(i-1)
3. SLP(i) = [AT(i)-S2(i)]/TC
   (IN THE NMC SYSTEM, ΔT = 1 AND BETA << 1, SO IN EQ. 2 THE APPROXIMATION IS MADE THAT BETA = 1/TC.

NOTES:

1. SEE PROCEDURE 2, "CALIBRATION OF X-RAY TYPE BREAKTHROUGH MONITORS" FOR ALGORITHM TO COMPUTE THE URANIUM COUNT.

Figure B1. SYSTEM BLOCK DIAGRAM AND ALGORITHMS.

This system of equations can be solved for Su as follows:

$$Su = p(C1-b)-q(C2-c)-r(C3-d),$$

or after dividing by p and rearranging terms,

$$Su/p = C1-(q/p)C2-(r/p)C3-(pb-qc-rd)/p \qquad (4)$$

where

$$p = (im-jl)/D \qquad (5)$$

$$q = (hm-jk)/D \qquad (6)$$

$$r = (ik-hl)/D \qquad (7)$$

$$D = eim+ghl+fjk-gik-ejl-fhm \qquad (8)$$

In Equation 4, Su/p represents the net uranium count obtained in the 1-min count interval. Refer to Fig. B1, System Block Diagram and Algorithms, for further clarification of this variable. The form of Equation 4 is consistent with the variable background correction algorithm in the NMC data acquisition module; i.e., the coefficient for C1 is 1; the coefficient for C2, which NMC calls BKG1 MULT, is preceded by a minus sign; the coefficient for C3, which NMC calls BKG2 MULT, is preceded by a minus sign; and the constant term, which NMC calls BKGND OFFSET, is preceded by a minus sign.

Therefore, the following identifications can be made for Case 1.

$$\text{BKG1 MULT} = q/p \tag{9}$$

$$\text{BKG2 MULT} = r/p \tag{10}$$

$$\text{BKGND OFFSET} = (pb-qc-rd)/p \tag{11}$$

The high-alarm level is conveniently thought of in terms of rate-of-buildup of uranium activity on the filter paper (e.g., 50 d/min/min). Expressed mathematically, this is:

$$\frac{dSu}{dt} = 50 \text{ d/min/min.}$$

However, according to Equation.4, the uranium count in the BTM is Su/p; so if a high-alarm set point of 50 d/min/min is desired, the actual value for the BTM parameter HIGH ALARM is computed as follows:

$$\text{HIGH ALARM} = \frac{d(Su/p)}{dt} = \frac{1}{p}\,\frac{dSu}{dt} = \frac{1}{p}*50$$

Therefore,

$$\text{HIGH ALARM} = (1/p)*(\text{Desired high alarm in d/min/min}) \tag{12}$$

2.2 CASE 2 - TWO ACTIVE WINDOWS

In most installations, radon will be the only interfering isotope so the BKG2 window should be disabled. This can be accomplished by setting the lower threshold above the upper threshold, thereby forcing the output from the BKG2 window to be zero. The following equations then apply.

$$(C1-b) = eSu + hSr \quad (13)$$

$$(C2-c) = fSu + iSr \quad (14)$$

$$C3 = d = 0 \quad (15)$$

$$Su = pC1-qC2-(pb-qc), \text{ or}$$

$$Su/p = C1-(q/p)C2-(pb-qc)/p \quad (16)$$

where

$$p = i/D \quad (17)$$

$$q = h/D \quad (18)$$

$$D = (ei-hf) \quad (19)$$

Therefore, the following identifications can be made for Case 2.

BKG1 MULT = q/p (20)

BKG2 MULT = 0 (21)

BKGND OFFSET = (pb-qc)/p (22)

HIGH ALARM = (1/p)*(Desired High Alarm in d/min/min) (23)

Remember to use Equations 17, 18, and 19 to compute the values for p and q for Case 2.

2.3 CASE 3 - TWO ACTIVE WINDOWS WITH BKG1 UNCALIBRATED

Another case of current interest is where the BTM radon window is set up for radon, but the radon channel cannot be calibrated because of insufficient radon activity (it is assumed the third window has been closed by inverting the thresholds or discussed above).

Referring to Equation 16, if the coefficient for C2, which is called BKG1 MULT in the BTM, is set to zero and the constant term, which is called BKGND OFFSET in the BTM, is set to b, then the right-hand side of Equation 16 becomes C1-b. According to Equation 13, if Sr = 0, then

$$eSu = C1-b.$$

Therefore, under the constraint that no radon is present, the BTM can be set up as follows:

BKG1 MULT = 0

BKG2 MULT = 0

BKGND OFFSET = b

HIGH ALARM = e*(Desired high alarm in d/min/min).

The system may be operated temporarily with this setup, but note that it will have no ability to reject radon daughter activity and may therefore give unwanted alarms until the radon channel is calibrated and the system is set up as described for Case 2.

2.4 CASE 4 - ONE ACTIVE WINDOW

In Case 4, the variable-background compensation algorithm will not be used at all. Both the BKG1 window and the BKG2 window will be closed by inverting the thresholds as described for Case 2. The following equations then apply:

$$C1-b = eSu \tag{28}$$

$$C2 = 0 \tag{29}$$

$$C3 = 0 \tag{30}$$

$$Su/p = C1-b \tag{31}$$

where p = 1/e.

Therefore, the following identifications can be made for Case 4.

BKG1 MULT = 0 (32)

BKG2 MULT = 0 (33)

BKGND OFFSET = b (34)

HIGH ALARM = (1/p)*(Desired High Alarm in d/min/min), (35)

where (1/p) = e.

APPENDIX C

PROCEDURE 3

STACK RADIOLOGICAL MONITORING PROJECT
CHECKING ALARM RESPONSE WITH AN ISOTOPIC SOURCE

1. INTRODUCTION

The purpose of this procedure is to check that the breakthrough monitor (BTM) is performing acceptably.

This procedure assumes the monitor is set up for normal operation as described in Procedure 2, Calibration of X-Ray Type BTMs. Refer to that procedure for definitions of terms.

2. PROCEDURE

1. Verify that parameters are correct.

Screen Fig. 2.1.4.3-A in NMC Instruction Manual

Q1 CONST	1.000 -01
Q2 CONST	9.000 -01
DEL1 CONST	1.000 -01
DEL2 CONST	9.000 -01
ALPHA CONST	6.250 -02
ALPHA LOWER	6.250 -02
ALPHA UPPER	6.250 -02
TIME CONST	2.000 +01

Screen Fig. 2.1.4.4 in NMC Instruction Manual

HIGH ALARM	Note 1	cpm/min
LOW ALARM	1.000 + 00	cpm
SCALER TIME	NA	Minutes
CONV CONST	NA	Ci/cpm
HIGH VOLTAGE	Note 1	Volts
FLOW MAINT	5.000 - 01	cfm

Screen Fig. 2.1.4.5 in NMC Instruction Manual

BK1 MULT	Note 1	
BK2 MULT	Note 1	
BKGND OFFSET	Note 1	cpm

Note 1: These values must match the calibration records for each BTM.

2. Install a clean filter paper.

3. Obtain the average of five 1-min counts from the center window and the Bkg 1 window if it is being used, and calculate the current value for BKGND OFFSET; call this value $\bar{A}$ (use the CURRENT DATA screen to get the count data).

4. Compute an effective source strength, S, as follows:

$$S = Su + (\bar{A} - \text{BKGND OFFSET})*p,$$

where

- Su = strength of the enriched uranium check source in d/min. This should be 3,000 d/m nominal.

- BKGND OFFSET is the numerical value currently installed in the BTM.

- p is the numerical value applicable to the current calibration of the BTM. See Procedure 2, Calibration of X-Ray Type Breakthrough Monitors for further details.

If the computed effective source strength lies outside the range of data in Table C1, the BTM should be recalibrated using Procedures 1 and 2 before Procedure 3 is used.

5. From Table C1, find the range of acceptable alarm times associated with the effective source strength S, and the allowable drift in sensitivity.

6. Insert the check source.

Table C1. Range of acceptable alarm time

Effective source strength, S (d/min)	Minimum allowable Alarm time (min)		Maximum allowable Alarm time (min)	
4,600	4.3	4	5.6	6
4,400	4.4	4	5.7	6
4,200	4.6	4	6.0	6
4,000	5.2	5	6.5	7
3,800	5.4	5	6.7	7
3,600	6.0	6	7.3	8
3,400	6.6	6	8.0	8
3,200	7.1	7	8.7	9
3,000	7.7	7	9.9	10
2,800	8.8	8	11.3	12
2,600	10.1	10	13.8	14

Notes:

1. The alarm time limits are based on data from 2,000 simulations and 99% confidence that 99% of the alarms will occur within the limits if the calibration is as expected. The minutes and tenths of minute data can be used for interpolation. The integer data should be used when checking the BTM since BTM data is updated at 1-min intervals.

2. If x% allowance is to be made for drift in calibration, then the minimum allowable alarm time should be found in Table C1 for an effective source strength x% larger than that computed in Step 4, and the maximum allowable alarm time should be found in Table C1 for an effective source strength x% smaller than that computed in Step 4.

7. Initialize the system near a 30-s tick, and record the time displayed on the cathode ray tube (CRT) at the next minute update.

8. Watch the slope data and record the time displayed on the CRT when the slope first exceeds the high-alarm set point. Note that the high-alarm function in the BTM is disabled for the first 10 min following an initialization so the alarm will activate when the slope exceeds the high-alarm set point or at the eleventh min, whichever is later, but always record the time when the slope first exceeds the alarm set point.

9. If the difference between the times recorded in Steps 7 and 8 is within the range of acceptable alarm times determined in Step 5 and the high alarm is actually generated, then the performance is acceptable; otherwise, the BTM should be recalibrated or repaired.

APPENDIX D

PROCEDURE 4

STACK RADIOLOGICAL MONITORING PROJECT

CHECKING THE SAMPLE FLOW SYSTEM

1. INTRODUCTION

The function of the sample flow system is to draw a 1-scfm sample of stack effluent through the filter paper. The system includes a mass flow controller to regulate the flow even when the filter paper gets dirty and partially plugged. The system can fail to perform because of (1) malfunctions in the flow controller, (2) a deterioration in pump performance, or (3) inleakage of ambient air. An obvious way to check the system for leaks is to plug the inlet to the breakthrough monitor (BTM) with the pump running and verify that there is no flow at the outlet. The manufacturer recommends not doing this because it exposes the radiation detector to low pressure and the beryllium windows of the X-ray detectors may bulge and develop cracks. DO NOT RESTRICT FLOW AT THE BTM INLET WITH THE PUMP RUNNING.

The following procedure will verify that the ability of the system to draw a 1-scfm sample through a dirty filter paper is near the design value. The approach is to use a dirty filter simulator in place of the regular filter paper. The dirty filter simulator, which consists simply of Whatman 1 filter paper, has a flow resistance which demands a pumping capacity near the pump design limits in order to maintain the design flow. The dirty filter simulator also reduces the pressure in parts of the system and maximizes any inleakage so it is easier to detect. The flow is checked both with and without the dirty filter simulator in place so the flow controller performance will be checked at both extremes of control valve position and sample pressure.

2. PROCEDURE

1. Connect a certified standard mass flowmeter to the BTM sample inlet such that fresh air will be drawn into the BTM through the standard mass flowmeter. Remove the BTM filter paper and make the following checks.

   a. With the pump off - verify that the BTM flow indication both at the outdoor assembly and the data acquisition module (DAM) is zero.

   b. With the pump on - verify that the indicated flow at the standard flowmeter as well as at both the outdoor assembly and the DAM is 1 scfm.

2. Install the Whatman 1 filter paper and make the following check.

   With the pump on - verify that the indicated flow at the standard flowmeter as well as at both the outdoor assembly and the DAM is 1 scfm.

3. Remove and discard the Whatman 1 filter paper. Use a new Whatman 1 filter paper for each check. Be sure to remove the Whatman 1 filter paper after the check so the operator can install a Whatman 41 filter for routine operation.

4. Notes

Inleakage ahead of the filter paper, the region marked A in Fig. 1, will dilute the stack sample during normal operation and, during this test, will cause the standard flowmeter to read lower than the BTM flowmeter. Inleakage between the filter paper and the flow controller, Region B in Fig. 1, will bypass the filter paper and reduce the stack sample flow during normal operation. During this test, inleakage in Region B will also cause the standard flowmeter to read lower than the BTM flowmeter. Inleakage between the flow controller and the pump, Region C in Fig. 1, may flood the pump to the extent that it cannot draw the required one scfm sample through a dirty filter or the dirty filter simulator. Leaks at Region C will not cause the standard flowmeter to read lower than the BTM flowmeter. Leaks downstream from the pump, Region D in Fig. 1, will not interfere with the stack sampling but may contaminate the BTM outdoor assembly.

The maintenance recall procedure describes how to make adjustments to the system and calls out the acceptable tolerances on the flow checks.

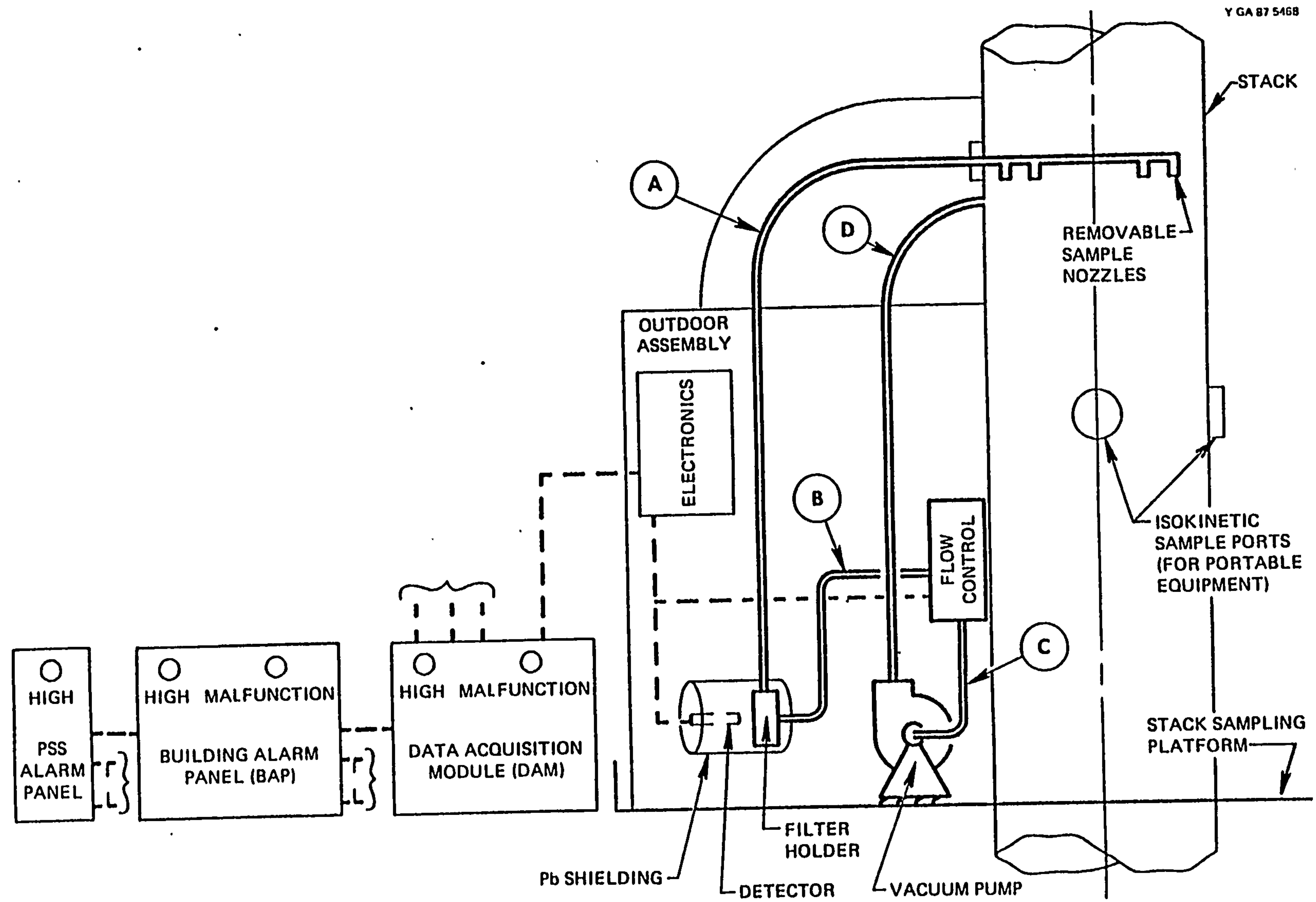


Figure D1. BREAKTHROUGH MONITOR/SAMPLER

APPENDIX E

CALIBRATION OF BETA DETECTOR-TYPE BREAKTHROUGH MONITORS

There is only window for beta counts in the BTM (i.e., the gross discriminator). Therefore, the equations found in Procedure 2, "Calibration of X-ray Type Breakthrough Monitors," Appendix A, for Case 4 - One Active Window, should be used to set the BTMs up for beta counting.

The activity of the cesium beta source (d/min/min) used for calibration should be corrected for the back scatter of beta particles from the stainless steel carrier. The ratio of counts obtained with a given amount of cesium on a filter paper to the counts obtained with the same amount of cesium on a stainless steel carrier is about 0.7. Therefore, the actual activity of the cesium source material on a stainless steel carrier should be multiplied by 1/0.7 to correct for beta back scatter.

In the above discussion, it is assumed that for the higher energy beta particles being counted from depleted uranium, the alpha/beta ratio is 1 and that the counting efficiency for beta particles from depleted uranium is the same as that for beta particles from cesium. The net effect of these assumptions will be a conservative alarm level (i.e., one which is somewhat lower than the target).